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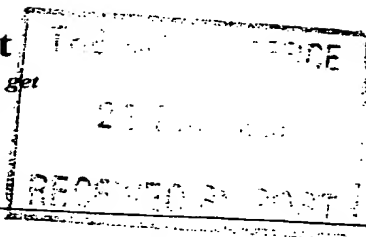
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1. Your reference

P22384/TCO/GMU

2. Patent application number
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3. Full name, address and postcode of the or of
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Bede Scientific Instruments Limited
Bowburn South Industrial Estate
Bowburn
Durham
DH6 5AD

Patents ADP number (if you know it)

If the applicant is a corporate body, give the
country/state of its incorporation

7073273001

United Kingdom

4. Title of the invention

"Method and Apparatus for Prolonging the
Life of an X-ray Target"

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom
to which all correspondence should be sent
(including the postcode)

Murgitroyd & Company
373 Scotland Street.
GLASGOW
G5 8QA

Patents ADP number (if you know it)

1198013

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Country

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Signature

Murgitroyd & Co.

Date

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12. Name and daytime telephone number of person to contact in the United Kingdom

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1 **Method and Apparatus for Prolonging the Life of an**
2 **X-Ray Target**

3

4 This invention relates to an X-ray generator, and in
5 particular to apparatus for prolonging the life of an
6 X-ray target used within an X-ray generator.

7

8 Known X-ray generators comprise an electron gun, an X-
9 ray target and an X-ray exit window. These generators
10 produce X-rays by accelerating electrons from the
11 electron gun into the x-ray target. X-rays are emitted
12 from the target through the exit window. Such
13 generators may be in the form of sealed X-ray tubes,
14 for example microfocus tubes, which are evacuated once
15 and then sealed off, or in the form of rotating anode
16 generators, which are permanently connected to vacuum
17 pumps and are continuously evacuated during operation.

18

19 A major limitation to the longevity of X-ray generators
20 is the lifetime of the target. All targets degrade
21 over time due to the effects of heat and roughening
22 caused by the electron bombardment. There are various
23 known methods for reducing these effects, including
24 cooling the back of the target with flowing water or
25 rotating the target so that no one area of the target
26 is continuously subjected to the electron bombardment.

1 Methods of increasing the cooling efficiency have been
2 proposed based on using high conductivity materials
3 such as diamonds. However, these methods are not in
4 common usage currently.
5

6 With known X-ray generators, it can take a number of
7 minutes after switching on the machine before it has
8 stabilised and is ready for use. As a result, many
9 generators are simply left running throughout the day,
10 so that the "warm-up" or stabilisation delay is
11 removed. This means that the electrons are focussed on
12 the target for long periods of time during each use of
13 the generator, which leads to accelerated degradation
14 of the target, even though the radiation produced by
15 the X-ray generator is used only for short periods.
16

17 In cases where the construction of the generator
18 permits, the target can be replaced. Where the
19 construction does not permit target replacement in a
20 routine procedure, then it is common practice to
21 discard the complete tube assembly making up the X-ray
22 generator.
23

24 In commercially available sealed tube and rotating
25 anode generators, there is no provision to control the
26 position of the beam on the target or to control the
27 quality, size or shape of the focal spot on the X-ray
28 target. The quality of the X-ray beam emitted can
29 deteriorate rapidly with prolonged use due to
30 contamination and damage to the target area under
31 continuous electron bombardment.
32

33 In the case of rotating anode generators, once
34 performance has degraded below a useful level,
35 replacement of the target is required. This entails
36 cost of replacement parts as well as significant down

1 time of the generator. In the case of sealed tube
2 generators it is necessary to discard the whole tube and
3 replace it with a new tube.
4

5 It is an object of the present invention to provide
6 means to lengthen the life of a target, and thereby to
7 lengthen the life of the X-ray generator. By
8 controlling the position and brightness of the beam,
9 the apparatus according to the present invention can
10 reposition and modify the area of focus of the beam.
11 Defocussing the beam reduces the flux per unit area of
12 electrons on the target. Repositioning the beam
13 enables a fresh area of the target to be exposed to
14 electrons. The lifespan of the target is prolonged by
15 either of these means, and the time interval between
16 replacements of the target or of the complete tube
17 assembly is increased.
18

19 A consequence of the approach of the present invention
20 is that the tube is only required to run in operational
21 condition with the target exposed to focussed electrons
22 when the operator requires the X-ray beam to be
23 produced.
24

25 According to the present invention, there is provided
26 an X-ray generator comprising an electron gun, electron
27 focussing means, a target and electronic control means,
28 wherein the area of the target on which the focussing
29 means causes electrons from said electron gun to
30 impinge comprises an X-ray source, the control means
31 being adapted to control the electron focussing means
32 so that the X-ray source on said target may be varied
33 in size and/or shape and/or position.
34

35 According to a first aspect of the invention the
36 control means includes a switching means to switch the

1 electron focussing means between a first unfocussed
2 state in which the X-ray source has a first area and a
3 second focussed state in which the X-ray source has a
4 second area smaller than said first area. The second
5 area may be a line, a spot or some other profile. The
6 first area may be a line of greater thickness, a spot
7 of greater diameter or some other shape.

8
9 Preferably said first area has a surface area at least
10 twice, more preferably four times, most preferably ten
11 times that of said second area.

12
13 According to a second aspect of the invention the
14 control means includes a switching means to switch the
15 electron focussing means between a plurality of
16 focussed states, whereby in each state the X-ray source
17 is in a corresponding discrete position on said target.
18 The X-ray source may be in the form of a line, a spot
19 or some other profile on the target.

20
21 The electron gun may comprise an evacuated tube around
22 which the electron focussing means is mounted outside
23 the vacuum. Alternatively the electron gun may
24 comprise an evacuated tube within which the electron
25 focussing means is mounted. The evacuated tube may be
26 a sealed vacuum tube or may be connected to a vacuum
27 pump which permits continuous evacuation during
28 operation of the generator.

29
30 The electron focussing means may comprise an x-y
31 deflection system for centring the electron beam in the
32 tube. The electron beam focussing means may further
33 comprise at least one electron lens, preferably an
34 axially symmetric or round lens, and/or at least one
35 quadrupole or multipole lens for focussing the electron
36 beam to a line focus and for steering the electron

1 beam.

2

3 The electron beam lenses may be magnetic or
4 electrostatic.

5

6 Preferably the target is metal, most preferably a metal
7 selected from the group Cu, Ag, Mo, Rh, Al, Ti, Cr, Co,
8 Fe, W, Au. The target surface may be orientated such
9 that the plane of the target surface is perpendicular
10 or at an angle to the axis of the X-ray tube.

11

12 According to a third aspect of the present invention
13 there is also provided a method for extending the life
14 of a target of an X-ray generator, wherein the
15 generator comprises an electron gun, electron focussing
16 means and a target, the method comprising the steps of:
17 firing electrons at the target such that the area of
18 the target on which the focussing means causes
19 electrons from said electron gun to impinge comprises
20 an X-ray source,
21 controlling the electron focussing means to move
22 between a first unfocussed state in which the X-ray
23 source has a first area and a second focussed state in
24 which the X-ray source has a second area smaller than
25 said first area, the intensity of electron impingement
26 in the first state being sufficiently low to reduce
27 target degradation, the intensity of electron
28 impingement in the second state being sufficiently high
29 such that the source produces a predetermined required
30 level of brightness and source size on the target. The
31 source may be a spot, a line or some other profile.

32

33 Preferably the electron beam current is substantially
34 the same in the first and second states, while the
35 intensity of the beam per unit area at the target is
36 lower in the first state than in the second state.

1 According to a fourth aspect of the present invention
2 there is provided a method for extending the life of a
3 target of an X-ray generator, wherein the generator
4 comprises an electron gun, electron focussing means and
5 a target, the method comprising the steps of:
6 firing electrons at the target such that the area of
7 the target on which the focussing means causes
8 electrons from said electron gun to impinge comprises
9 an X-ray source,

10 controlling the electron focussing means to move
11 between a plurality of focussed states, whereby in
12 each state the X-ray source is in a corresponding
13 discrete position on said target, such that the
14 intensity per unit area in each discrete position is
15 substantially constant, and such that there is no
16 overlap on the target between the discrete positions
17 corresponding to each focussed state. The source may
18 be a spot, a line or some other profile.

19
20 The lack of overlap between the discrete positions on
21 the target means that a fresh area of target is used as
22 a source each time the electron focussing means moves
23 to a new state. The control of the electron focussing
24 means may be manual but is preferably electronic, so
25 that each discrete position corresponds to a pre-
26 programmed control signal applied to the electron
27 focussing means.

28
29 An embodiment of the invention will now be described,
30 by way of example only, with reference to the
31 accompanying figures, where:

32
33 Fig. 1 shows a schematic longitudinal section through
34 an X-ray generator according to the invention suitable
35 for use with a close coupled X-ray focussing system
36 (not shown);

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Fig. 2 shows a schematic arrangement of an X-ray generator in the focussed state;

Fig. 3 shows a schematic arrangement of an X-ray generator in the defocussed state;

Fig. 4 shows a schematic arrangement of an X-ray generator with the target in a first focussed position;

Fig. 5 shows a schematic arrangement of an X-ray generator with the target in a second focussed position;

Figs. 6(a) and 6(b) shows schematically a side view and plan view respectively on a sealed tube X-ray generator according to the invention; and

Figs. 7(a) and 7(b) shows schematically a side view and front view respectively on a rotating anode X-ray generator according to the invention. .

With reference to Fig. 1, the X-ray generator 1 comprises an evacuated and sealed X-ray tube 2, containing an electron gun 3 and an X-ray target 4. The tube 2 has an exit window 6 through which X-rays are emitted from the target. Although the embodiment illustrated in Fig. 1 has a window 6 in front of the target 4, it is to be understood that the invention is applicable to other embodiments, for example X-ray generators in which the X-rays are emitted behind the target 4. The exit window does not form part of the invention and is not further described.

The tube 2 is contained within a housing 13. The generator 1 also includes a system 7 for focussing and

steering the electron beam onto the target 4.

The focussing and steering system is capable of producing a well focussed beam of electrons impinging on the target 4. The electron beam may be focussed into a spot or a line, and the dimensions of the spot and line as well as its position may be changed electronically. In typical X-ray applications a spot focus having a diameter falling in the range 1 to 100 μm , generally 5 μm or larger, may be required. Alternatively a line focus may be achieved whose width falls in the range 0.4 mm to 1.0 mm, and length in the range 5 mm to 15 mm.

The electron beam is produced by an electron gun 3 consisting of a Wehnelt electrode and cathode. The cathode may be a filament of tungsten or alloy, for example tungsten-rhenium, having either a hairpin or a staple shape. Alternatively the cathode may be an indirectly heated activated dispenser cathode, which may be flat or of other geometry, for example a rod with a domed end. The dispenser cathode has the advantage of extended lifetime and increased mechanical strength. With a flat surface the dispenser cathode has the further advantage of requiring only an approximate degree of alignment in the Wehnelt electrode.

Primary focus is achieved by an anode at a suitable distance from the electron gun.

The electron beam from the gun is centred in the X-ray tube 2 by a centring coil 14 or set of quadrupole lenses. Alternatively it may be centred by multipole lenses. Alternatively mechanical means may be used to centre the electron beam. The centring lens or coil 14

1 may be omitted, where the electron gun 3 is such that
2 it produced an electron beam which is sufficiently
3 aligned within the tube 2.

4

5 The electron beam is then focussed to a spot of varying
6 diameter. Focussing down to a diameter of less than 5
7 μm or better may be achieved by an axial focussing lens
8 15 of the quadrupole, multipole or solenoid type.

9

10 The spot focus may be changed to a line focus with a
11 stigmator lens 16, which may comprise a further set of
12 quadrupole or multipole lenses. Lines with an aspect
13 ratio of greater than 10:1 are possible. A line focus
14 spreads the load on the target. When viewed at a
15 suitable angle, the line appears as a spot.

16

17 The lenses 15, 16 are preferably magnetic, but may be
18 electrostatic. All the lenses are electronically
19 controlled, enabling remote control and continuous
20 alignment and scanning of the focal spot. Change from
21 spot to line focus and change of beam diameter are also
22 controlled remotely by varying the control signals to
23 the electron focussing devices 7.

24

25 The electronic control of the lenses enables the
26 electron beam to be defocussed and/or repositioned on
27 the target 4. As a result, the high intensity focal
28 spot of the electron beam is not continuously being
29 directed at one particular area of the target 4, which
30 means that the rate of degradation of the target will
31 be significantly slower than with known X-ray
32 generators. The electron beam is only focussed at high
33 intensity when the X-ray beam is required.

34

35 The actions of defocussing and refocussing the electron
36 beam are activated either at will by the operator by

1 varying the power of the focussing coils, preferably by
2 an electronic switch control, or automatically by the
3 action of a shutter on the output side of the X-ray
4 beam or other external event defined by the operator.

5
6 The target 4 is a metal, for example Cu, but it can be
7 another material depending on the wavelength of the
8 characteristic radiation required, for example Ag, Mo,
9 Al, Ti, Rh, Cr, Co, Fe, W or Au. The target 4 is
10 either perpendicular to the impinging electron beam, or
11 may be inclined to decrease the absorption of the
12 emitted X-rays.

13
14 In an example of a preferred embodiment of the present
15 invention, the cathode is at negative high voltage and
16 the electron gun 3 consists of a filament just inside
17 the aperture 11 of a Wehnelt grid which is biased
18 negatively with respect to the filament. The electrons
19 are accelerated towards the anode which is at ground
20 potential and pass through a hole in the latter and
21 then through the tube 2 towards the target 4. Two sets
22 of beam deflection coils 14, which may be iron-cored,
23 are employed in two planes separated by 30 mm, mounted
24 between the anode of the electron gun 3 and the
25 focussing lens 15 to centre the beam. Between the
26 focussing lens 15 and the target 4 is an air-cored
27 quadrupole magnet which acts as a stigmator 16 in that
28 it turns the circular cross-section of the beam into an
29 elongated one. This quadrupole 16 can be rotated about
30 the tube axis so as to adjust the orientation of the
31 line focus. The beam can be moved about on the target
32 surface 4 by controlling the currents in the four coils
33 of the quadrupole 16.

34
35 With reference to Figs. 2 and 3 there is shown a tube
36 2, electron gun 3 and target 4, together with electron

focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 2, the electron beam 30 is focussed by the focussing means 7 so that it forms a relatively small spot 20 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to the second unfocussed state as shown in Fig. 3, the electron beam 31 has the same power, but the focussing means does not focus the beam 31 so tightly, so that it forms a relatively larger spot source 21 on the target 4. In this state the X-ray generator is in standby mode and the intensity per unit area at the target 4 is greatly reduced. The consequent localised degradation of the target, which depends on local intensity per unit area, is also reduced.

With reference to Figs. 4 and 5 there is shown a tube 2, electron gun 3 and target 4, together with electron focussing means 7, which are discussed in more detail above. In the first focussed state, as shown in Fig. 4, the electron beam 32 is focussed by the focussing means 7 so that it forms a relatively small spot source 22 on the target 4, the spot source being the required size for generation of X-rays for the intended purpose. In this state the X-ray generator is operational and the brightness of the emitted X-ray beam may be controlled by varying the applied power to the tube. When the generator is switched to a second focussed state, as shown in Fig. 5, the electron beam 33 has the same power, but is focussed by the focussing means to a second spot source 23 on a different part of the target 4. The spot source 23 is the required size for

1 generation of X-rays for the intended purpose, and will
2 generally be the same size as the spot source 22 in the
3 first state. There is no overlap between the positions
4 of spot sources 22 and 23.

5
6 In practice there may be further operational states in
7 which the spot source is the same size as spot sources
8 22, 23 but in different, non-overlapping locations. It
9 may be possible to fit as many as ten or more non-
10 overlapping sources on a target, thus giving a ten-fold
11 increase in the life of the target. The focussing
12 means 7 may be adjusted manually to move the spot
13 source, or the control signals required to adjust the
14 focussing means may be stored electronically, so that
15 the apparatus automatically steps to the next state
16 when an operator indicates that the position of the
17 focus should be changed. The stepping could be
18 automatic after a predetermined elapsed operating time
19 at a particular state, for example an elapsed time
20 counter could be built into the apparatus to show a
21 warning signal when the predetermined operating time is
22 exceeded. The operator would then be alerted to switch
23 the apparatus to the next state.

24
25 Although the examples of Figs. 2 to 5 have been
26 described with reference to spot sources, it is to be
27 understood that the invention is equally applicable to
28 line focus sources. Furthermore the illustrated
29 embodiments have been described with a focussing means
30 which comprises a centring lens, a focussing lens and a
31 stigmator lens. It is to be understood that the
32 functions of any of the three lenses may be combined in
33 one or more lenses, and that the order of the
34 components of the focussing means may be varied.

35
36 Figs. 6(a) and 6(b) shows schematically a side view and

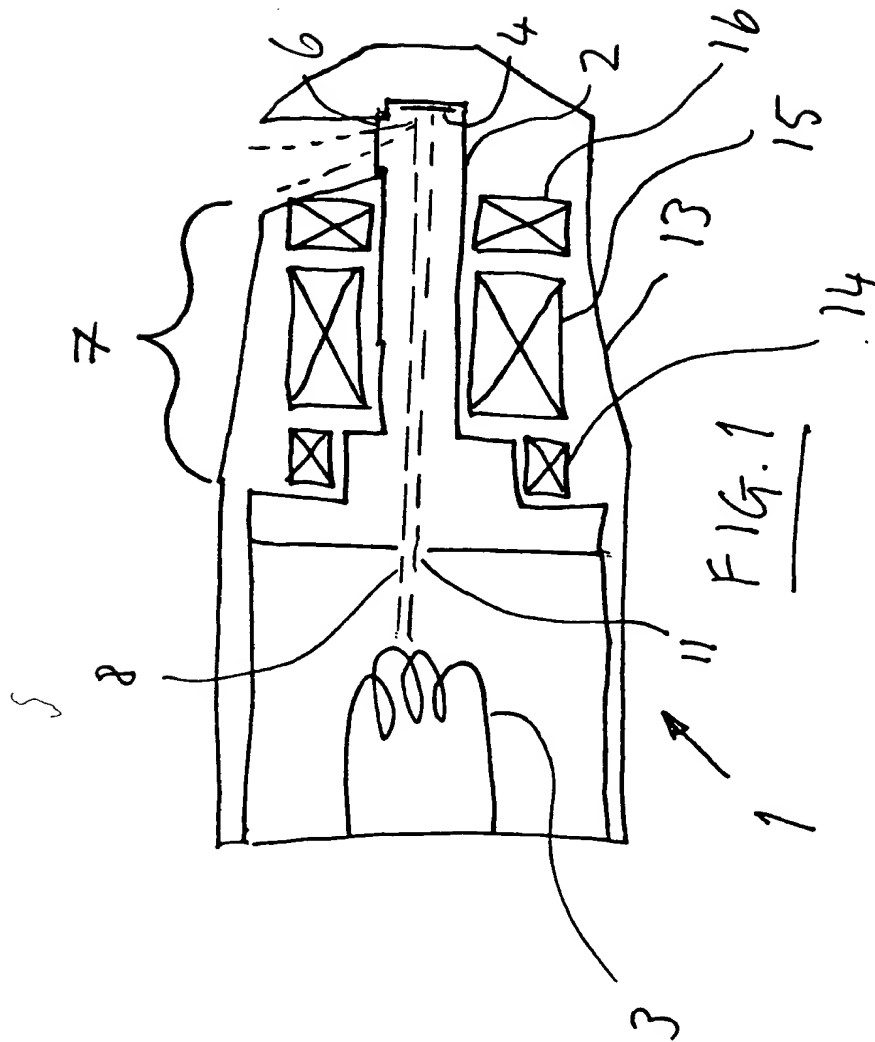
1 plan view respectively on a conventional sealed tube X-
2 ray generator. The generator comprises a sealed vacuum
3 enclosure 30 fabricated from glass and metal, or from
4 ceramic and metal. Inside the enclosure 30 is an
5 electron gun 31 and a target 32. Adjacent to the
6 target are X-ray transparent windows 33, through which
7 X-rays 36 are transmitted. Surrounding the vacuum
8 enclosure between the electron gun 31 and target 32 is
9 an electrostatic or electromagnetic lens 34. Behind
10 the target is a conventional water cooling arrangement
11 35.

12
13 The lens 34 comprises one or more sets of focussing
14 coils arranged outside the vacuum envelope of the X-ray
15 tube 30. The coils forming the lens 34 may be
16 electromagnetic or electrostatic. At least one of the
17 sets of focussing coils is used to steer the electron
18 beam from the electron gun 31 onto the target 32, and
19 may also be used to change the shape and/or size of the
20 beam. A switch control (not shown) may be provided
21 which upon operation automatically provides the
22 electrical power to the coils so as to steer the
23 electron beam to a larger focus or to a different point
24 on the target. This enables the power density loading
25 on the target 32 to be reduced when the X-rays are not
26 being used, or for new areas of the target 32 to be
27 periodically exposed when the previously exposed area
28 becomes damaged or degraded. In Fig. 6 the coils 34
29 are shown as being external to the vacuum. In this way
30 it is possible for the focussing coils 34 to be
31 retrofitted to an existing generator, in order to
32 prolong the life of the generator. However the scope
33 of the invention includes the case where the coils 34
34 are built in to the generator and provided inside the
35 vacuum enclosure 30.

1 Figs. 7(a) and 7(b) shows schematically a side view and
2 front view respectively on a conventional rotating
3 anode X-ray generator. The generator comprises a
4 continuously pumped vacuum chamber 40 containing an
5 electron gun 41 and a target 42 deposited on a
6 cylindrical anode 43 which rotates at high speed.
7 Adjacent to the anode are X-ray transparent windows 44,
8 through which X-rays 46 are transmitted. Surrounding
9 the vacuum chamber between the electron gun 41 and
10 target 42 is an electrostatic or electromagnetic lens
11 45. The anode 43 is water cooled (not shown). The
12 rotation of the anode 43 dissipates more effectively
13 the heat generated on the target 42, so that increased
14 power loading of the target and hence increased X-ray
15 brightness are possible.

16
17 The electrostatic or electromagnetic lens 45 comprises
18 one or more sets of focussing coils arranged outside
19 the vacuum chamber 40. The coils 45 serve the same
20 purpose as the coils 34 described with reference to
21 Fig. 6 above, and may also be retrofitted or fitted
22 within the vacuum chamber, ie the coils may be internal
23 or external.

24
25 These and other modifications and improvements can be
26 incorporated without departing from the scope of the
27 invention.
28



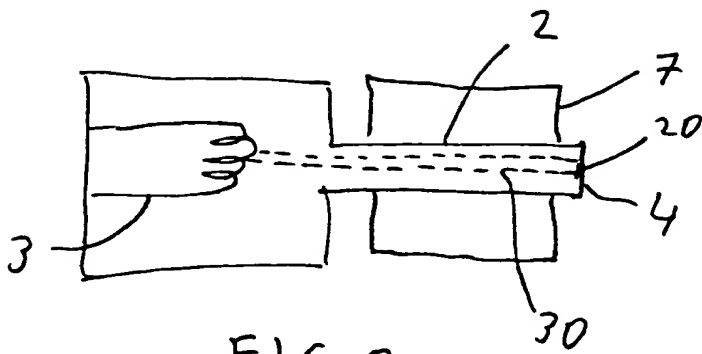


FIG. 2

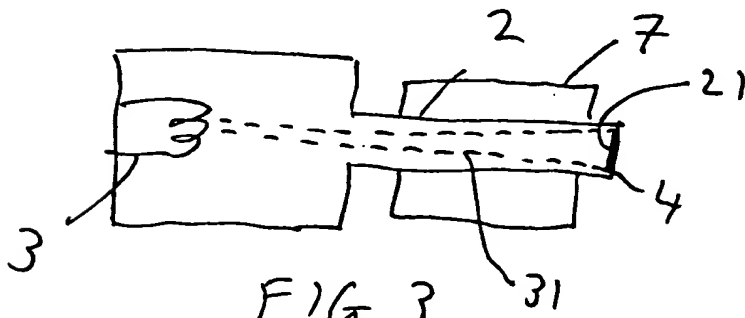


FIG. 3

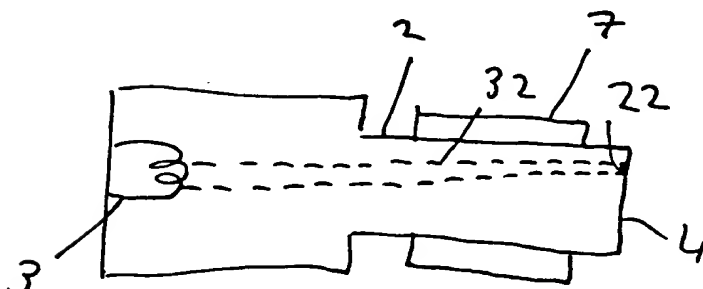


FIG. 4

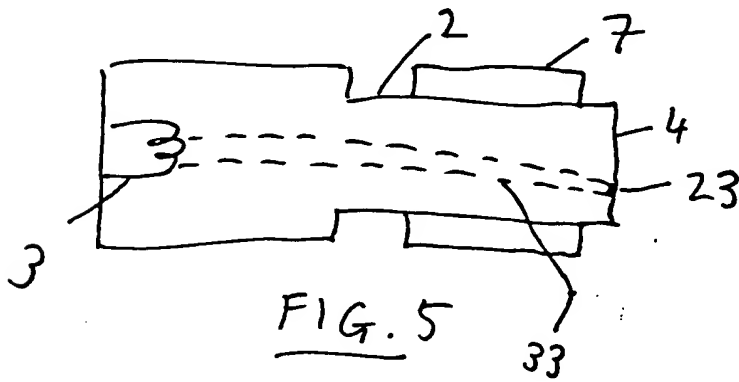


FIG. 5

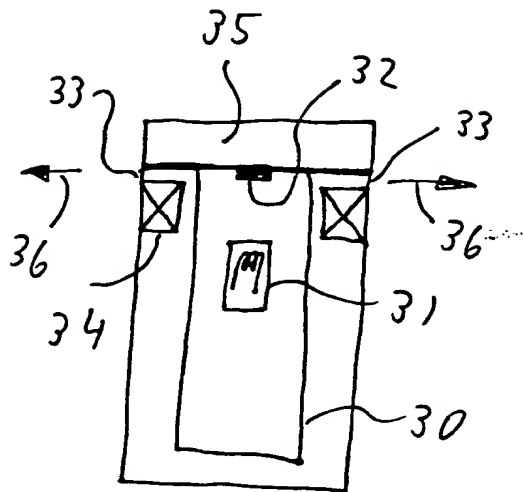


FIG. 6(a)

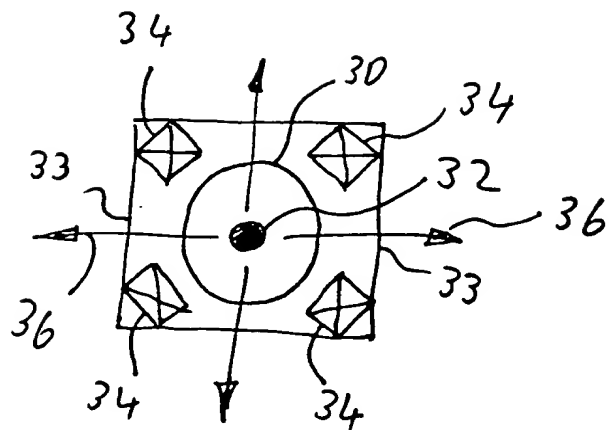


FIG. 6(b)

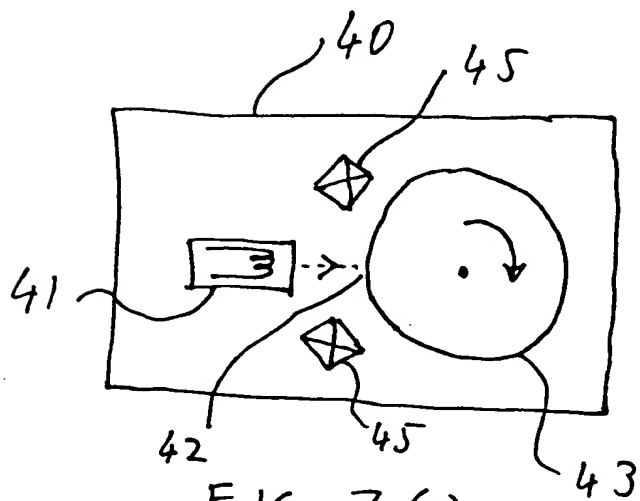


FIG. 7(a)

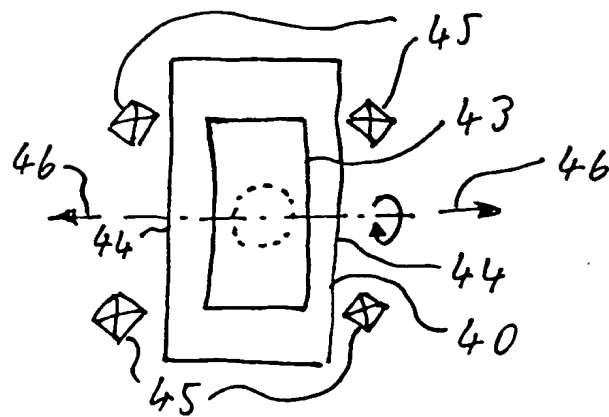


FIG. 7(b)

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